MASSACHUSETTS INSTITUTE OF TECHNOLOGY
A. I. LABORATORY

Artificial Intelligence
Memo No. 273 January 1973

THE LITTLE ROBOT SYSTEM

David Silver

Work reported herein was conducted at the Artificial Intelligence Laboratory, a Massachusetts Institute of Technology research program supported in part by the Advanced Research Projects Agency of the Department of Defense and monitored by the Office of Naval Research under Contract Number N00014-70-A-0362-0003.

Table of Contents

General description of the Little Robot System

The Little Robot System provides for the I.T.S. user a medium size four degree of freedom six axis robot which is controlled by the PDP-6 computer through the programming language Lisp. The robot includes eight force feedback channels which when interpreted by the PDP-6 are read by Lisp as the signed forces applied to the end of the fingers. The first six forces are the X,Y and Z forces and the torques around X,Y and Z . The other two forces are the grippers and the vice grippers. The three X,Y and Z forces and three torques are computed from six numbers read in from six L.V.D.Ys (Linear Variable Differential Transformers) arranged three in the vertical and three in the horizontal plane within a stress strain spring loaded wrist. The grip is read in from a strain guage mounted on the stationary reference finger. The relative position between the motor shaft and the vice shaft is determined through means of two potentiometers to measure the vice force. The two shafts are coupled by a spring.

The force feedback wrist has a dynamic range of about one pound and a resolution of about 0.25 ounces with not more then one ounce of hysteresis. The grip can measure one pound of gripping force and the vice can measure about three pounds of gripping force.

The robot has its six axes split up into two parts. The first half consists of a nine square inch plate which moves in two perpendicular directions for X and Y. The computer controlled vice is mounted on the plate in one corner. The other half consists of the Z axis which is mounted over the plate. The Z axis hangs down over the plate and has a vertical travel of five inches. On the end of the Z axis is mounted the stress strain wrist and on the end of the wrist is mounted the hand which can rotate and grip. Until a hardware modification is made only the center six of the nine square inch work-space can be used.

The three main axes (X,Y and Z) have a resolution of 0.001 inches and a positioning repeatability of plus or minus 0.003 inches. The X,Y plate is flat and level with respect to the end of the fingers to less than 0.010 inches. The robot can be positioned anywhere within the six by six inch work space in less than twenty seconds.

The Little Robot Controller is mounted on the right hand side of the table where the robot lives. The plexiglass panel on the front of the controller has some lights, switches, and a whistle which goes "beep" when the robot feels pain. The controller contains six power amplifiers so the computer can control the speed of each motor associated with each of the six axes. It also contains appropriate interfacing of six high resolution potentiometers to measure the position of the six axes, making it possible for the computer to servo to the desired positions of all six axes.

Six L.V.D.T. amplifiers, a strain guage amplifier and a differential amplifier are contained within the controller to interface the wrist, reference finger, and the vice force input. Also contained in the controller are some electronics which monitor all eight forces felt by the robot. If any of the forces exceeds the threshold of pain, the controller is told to shut off all six motors and to start beeping the whistle. Because of the simple minded nature of this safety feature, the robot cannot back away from pain and will get itself latched up merely by squeezing too hard with the grip or vice, or by moving the arm down into the table, etc. This latching up problem is something that the user shouldn't have to encounter because the program running in the PDP-6 contains a model of pain which is both aware of the latch up problem and allows the robot to move away from pain. If the robot does get into this latched up state it should be regarded as a bug in the Little Robot System and you should turn off the controller. By the way, the whistle will still continue to beep so you might also flip off the switch labeled "ALARM" before it drives you nuts.

Using The Little Robot in Lisp

Start the PDP-6 running, then type:

LISPK

(FASLOAD MINOPN FASL COM)

(OPENMINI)

(SETM CALB -1)

Sometimes LISP and the Compiler are incompatible, in which case when you do the FASLOAD, LISP will type out a warning message. Try OLISP, and if that fails then try (UREAD MINOPN >).

OPENMINI will return NIL after the PDP-6 is loaded and running.

"CALB" will become zero when the calibration is done.

Do not type on the teletype or lean on or bump the table while the robot is calibrating itself! If you should disturb the robot while it is calibrating itself, then recalibrate. Part of the calibrating sequence consists of mapping the null force for all orientations of the hand. Therefore, bumping the arm while calibrating will cause the robot to feel a ghost force whenever it passes through that same orientation. The robot can feel building tremors.

Before you flip the motor switch to on always check the following:

1) Check the five red power supply indicator bulbs labled +15 -15 -10 +25 -25 . If any of these indicators are out, turning the motor switch on can cause damage to the hardware.

2) Check the switch labled "ALARM" and make sure it is on. If when you flip it on the alarm starts to beep, or any other time the alarm starts beeping give up, and let me know. Make sure to flip off the alarm switch and the motor switch before you leave.

3) Check and make sure that LISP has returned NIL after you have typed (OPENMINI) or (REOPENMINI).

Flip the motor switch on. The initial state of the Little Robot variables are such that the arm will assume a position which is centered over the table as soon as the motor switch is turned on.

Theoretically, the Little Robot can not be damaged under program control. But please note the following: try not to apply more than one or two pounds of force to either the X,Y bed or the hand and wrist. When setting up the scene, for example, if your shirt sleave were to get caught on part of the hand as you pulled your hand away, you might sprain the robot's wrist. Remember that the wrist is only supporting the hand with four pieces of 0.04 inch piano wire.

LISP Functions

SETM - The LISP function SETM (SET Mini) of two arguments is used to set variables. For example, (SETM XDES 3.0) will move the arm to a position three inches on the X axis.

GETMF - The function GETMF (GET Mini Floating point) of one argument is used to read variables. For example, if XDES is 3.0, (GETMF XPOS) might return the value 2.999 meaning that the potentiometer is measuring the X axis to to be 0.001 inches from its destination.

GETM - (GET Mini fixed point). Care should be taken to read fixed point variables with GETM and floating point variables with GETMF.

WAIT - The function WAIT of one argument first waits for the variables in the PDP-6 to become consistent and then evaluates its argument every thirtieth of a second and will sleep until evaluating the argument returns T.

SEQ - The function SEQ (Sort of EQual) of three arruments returns the value T when the first two arguments are equal to within the tolerance of the third argument, otherwise NIL. The followieg example will first set the arm's destination to 1.5 inches above the table and will then sleep until the arm actually gets to within three mils of 1.5 inches above the table.

```
(SETM ZDES 1.5)
(WAIT '(SEQ (GETMF ZDES) (GETMF ZPOS) 0.003))
```

OPENMINI - Type (OPENMINI) to load and start the PDP-6 robot program.

REOPENMINI - Type (REOPENMINI) to reload and start the PDP_6 program.

CLOSEMINI - Type (CLOSEMINI) to close the PDP-6.

Thn I/O Variablns

You may find the list of variables to be somewhat random bacause of the flags and the apparnnt redundanca of somn of tha variablns. The fnllowing list is the subsat nf all tha variablea which should most commonly bn usnd. You may need to use some of the nther variablns if you raquire tolaranans which are close to or are limitad by the snecifcations llatad in the beginning.

Output vsriablns (Abbrnviated descriptinn)

CALB - When set to -1 runs Calibration program.
RESET - When snt to -I Rnsnts the variablns.
XDES-VDES - Floating point Destination.
XFDS-VFDS - Fixad point Force Destination.
XFRE-VFRE - Whnn snt to 0 servos to RFS.
Whnn set to -1 servos to FOS.

Input variablns (Abbrnviatnd descrintion)

XPOS-VPOS - Floating point Positions.
XFRS-VFRS - Fixed point Forcns.
XTRC-ZTRC - Fixnd point Torouns.
XDLT-VDLT - Fixad point Deltas.

Input variablns

TIC — Is incremated avary 1/60 sec in tha variablns update loop.

Done -

XDLT, YDLT, ZDLT, RDLT, ODLT, VDLT — Ths Dnltaa are fixed point numbers wblch are the diffnrencas betwnan thn dnstinations and thn currnnt positiona in pot units. (Pot units bning tha numbars sent out and read in from the A/D snd D/A multiplexor.)

XPOS
YPOS
ZPOS
RPOS
GPOS
VPOS

The Positions are floating point numbers which are the current positions of the axes as seen by the potentiometers in units of inches for the linear axes and radians for the rotate axis.

XFRS
YFRS
ZFRS
RFRS
GFRS
VFRS

The Forces are fixed point numbers which are the signed forces being applied to the hand. These numbers are corrected to read closer to zero for all orientations of the hand.

XTRC
YTRC
ZTRC
RTRC
GTRC
VTRC

The Torques are fixed point numbers which are the magnitude and sign of the torques around the three force axes. For examplr if the hand was rotating a nut for the purpose of screwing it on to a bolt, you could get the torqur being applied to the bolt from ZTRC.

XVLS
YVLS
ZVLS
RVLS
GVLS
VVLS

The Velocities are fixed point numbers which are the velocities of the axes.

1RFRS
2RFRS
3RFRS
4RFRS
5RFRS
6RFRS
GRFRS
VRFRS

The Raw Forces are fixed point numbers read in by the A/D. They are the forces measured by the six L.V.D.T's. in the wrist.

A/D input from strain guage.
A/D input from pot assembly.

1ZFRS
2ZFRS
3ZFRS
4ZFRS
5ZFRS
6ZFRS
GZFRS
VZFRS

The Zerned forces are fixed point numbers which are the forces measured by the L.V.D.T's strain guegs and pots which are corrected to read closer to zero for all orientations of the hand.

XPPOS
YPPOS
ZPPOS
RPPOS
GPPOS
VPPOS

Thr Pot Positions are fixed point numbrrs read in from the pots by thr A/D.

Output Vnriables

CALR

Calb should hr srt to -1 first thing after lneding end onrning thr Littlr Rnbot for thr nurnose nf calibrating end zern cnterering the force inputs. Calb will become zrro egain when thr calibretion is comnleted.

XPDES
YPDES
ZPDES
RPDES
GPDES
VPDES

Thr Pot unit Destinetion snrcifird in fixed point will have effect only if FRE (Limp mode flag) is zerp and CLMD (Calibrete mode flag) is zero.

XGAN
YGAN
ZGAN
RGAN
GGAN
VGAN

The gains are fixed point numbers which determine the position servo gain only when FRE (Limn mode flag), is zero.

XFGN
YFGN
ZFGN
RFGN
GFGN
VFGN

Thr Force Gains are fixed point numbers which drtermine thr gain in limp mode end err only effective when FRE (Limo mndr flagl is -1.

XFRE
YFRE
ZFRE
RFRE
GFRE
VFRE

When FRE (Free) is eet to -1 the exis is in limp mnde end the axis will servo to e deelred force FDS (Force destination).

XDES
YDES
ZDES
RDES
GDES
VDES

Thr Destinetion is specified in floeting point in units of inches for the linear axes and redians fnr thr rotate exis. DFS is effrctive only whrn FRF (Limp mndr flag) is zero and CLMD (Calibrete mode flag) is -1.

XCLMD
YCLMD
ZCLMD
RCLMD
GCLMD
VCLMD

CLMD is the suffix for six flags which when set to zero cause the arm to servo to the PDFS (Pot unit Destination) and when CLMD is set to -1 causes the arm to servo to DES (Floating point Destination).

XFDS
YFDS
ZFDS
RFDS
GFDS
VFDS

The FDS (Force Destination) is effective when FRE (Limp mode flag) is -1. FDS is set to a fixed point number causing the axis to move in such a way so as to servo the force to the FDS.

ARMON

Is a flag which when set to -1 softwarily turns the arm on and when set to zero turns the arm off.

RESET

Is a flag which when set to -1 restores all the robot variables to their initial state. Reset will return to zero when the reset is done.

EXAMPLES

```
(SETQ UP 4.0)
(SETQ OPN 1.5)
(SETQ SQZ 2000)
(SETM RFSFT -1)
(WAIT '(ZFROP (GETM RFSFT)))
(SETM RDES 0)
(WAIT '(SEQ (GETMF RPOS) 00.005))

(DEFUN MOVETO (X Y Z)
(SETM ZDES UP)
(WAIT '(SEQ (GETMF ZPOS) UP 0.005))
(SETM XDES X)
(SETM YDES Y)
(WAIT '(AND (SEQ (GETMF XPOS) X 0.005) (SEQ (GETMF YPOS) Y 0.005)))
(SETM ZDES Z)
(WAIT '(SEQ (GETMF ZPOS) Z 0.005))
NIL)
```

```
(DEFUN GRIP ()
(SETM GFDS SOZ)
(SETM GFRE -1)
(WAIT '(SEQ (GETM GDLT) 0 20)
NIL)

(DEFUN UNGRIP ()
(SETM GDES OPN)
(SETM GFRE 0)
(WAIT '(SEQ(GETM GDLT) 0 20 )
NIL)
```